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CoPt AND FePt THIN FILMS FOR HIGH DENSITY RECORDING MEDIA

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Abstract

Granular CoPt/C and FePt/C films, consisting of nanoparticles of the highly anisotropic fct CoPt (FePt) phase embedded in a carbon matrix, were made by co-sputtering from pure $Co_{50}Pt_{50}$ ($Fe_{50}Pt_{50}$) and C targets using a tandem deposition mode. The as-made films showed a disordered face centered cubic (fcc) structure, which was magnetically soft and had low coercivity. Magnetic hardening occurred after heat treatment at elevated temperatures, which led to increase in coercivity with values up to 15 kOe. The hardening originated from the transformation of the fcc phase to a highly anisotropic face centered tetragonal phase (fct) with anisotropy $K > 10^7$ erg/cm^3. Transmission electron microscopy studies showed FePt particles embedded in C matrix with a particle size increasing from below 5 nm in the as-made state to 15 nm in the fully annealed state. These results are very promising and make these materials potential candidates for high-density magnetic recording.

1. Introduction

FePt and CoPt alloys with compositions close to equiatomic have been studied extensively in the past, as possible candidates for permanent magnets [1], because of the large value of magnetocrystalline anisotropy of the ordered fct phase. This resulted in coercivities greater than 5 kOe. These alloys undergo a phase transformation at 1300°C for FePt and 800°C for CoPt, from a disordered face centered cubic (fcc) phase at higher temperatures to an ordered face centered tetragonal (fct) phase at lower temperatures. Recently these alloys were prepared in the form of thin films receiving considerable attention for magnetic recording and magneto-optical recording applications [2].

Requirements for higher magnetic recording density with low noise impose the need of a material consisting of magnetically isolated grains with size below 10 nm [3]. In such small grain sizes high magnetocrystalline anisotropy is needed to avoid thermal

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fluctuations and demagnetizing fields that tend to destabilize the magnetization of the recorded bits [3]. Current studies have been focused on nanocrystalline rare-earth compounds and CoPt and FePt because of their high anisotropy. Granular CoPt/C films consisting of Co-rich hexagonal Co-Pt particles in a C matrix have been reported by Delaunay et al. [4]. However, the films had a low coercivity because of the lower anisotropy of the hexagonal Co-rich phase. We have recently started a program to obtain nanocomposite CoPt/M and FePt/M (M = Ag, C) films consisting of magnetically hard CoPt (FePt) nanoparticles in a non-magnetic matrix. In this study we prepared nanocomposite CoPt/C and FePt/C films consisting of the highly anisotropic tetragonal phase with coercivities in the range of 2-9 kOe and studied the effects of particle size, temperature and interparticle interactions on the coercivity.

2. Experimental

The granular structure was obtained by first depositing CoPt/C or FePt/C in a multilayer form (consisting of 100 repetitions) and subsequently annealing the samples in the temperature range of 500-900°C. The films were prepared by magnetron sputtering deposition from pure 1.3 inch targets of $Co_{50}Pt_{50}$ or $Fe_{50}Pt_{50}$ and C. The base pressure of the chamber was 3×10^{-8} Torr and high purity Ar (99.9999%) was used for deposition at ambient temperature with a pressure of 5 mTorr. The substrates used were Si(100), 600 μm thick with a naturally grown oxide on the surface. A 150 Å buffer layer of C was used to ensure similarity of growth conditions. The C layers were sputtered using a power of 60 W DC at a rate of 0.3 Å/sec. For CoPt and FePt a DC power of about 10 W gave a growth rate of 1.4 Å/sec and the resulting stoichiometry of the layers was found to be $Co_{54}Pt_{46}$ and $Fe_{49}Pt_{51}$. The chemical composition of CoPt and FePt as-made films was checked by energy dispersive x-ray analysis. X-ray diffraction (XRD) spectra were collected with a PHILIPS powder diffractometer using Cu-K_α radiation. Magnetic hysteresis loops were measured with an Oxford MagLab VSM and a Quantum Design MPMSR2 SQUID magnetometer. The microstructure was examined with a Philips CM20 and a Jeol JEM-2000 FX TEM transmission electron microscopes (TEM).

3. Results and Discussion

All the as-made films were magnetically soft and became hard after annealing at temperatures between 600-780°C. The development of hysteresis loops was found to be sensitive to the layer thickness. A summary of the hysteresis loop parameters of CoPt/C samples, with different bilayers thickness, after annealing at different temperatures and times

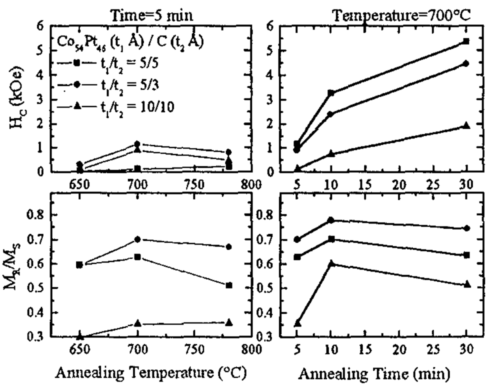

Figure 1. Coercivity and reduced remanence as a function of annealing temperature and time.

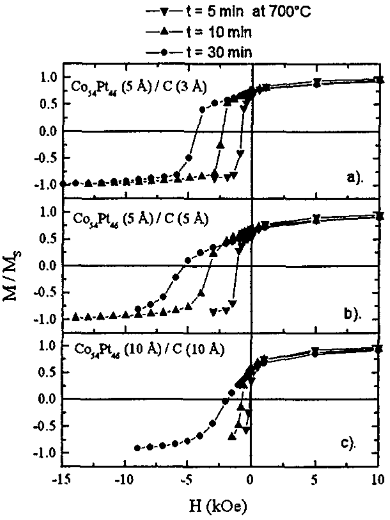

Figure 2. Demagnetization curves for $Co_{54}Pt_{46}$ (t_1 Å) / C (t_2 Å) samples annealed for 5-30 minutes at 700°C with different t_1, t_2.

is shown in figure 1. Higher reduced remanence (M_r/M_S) reaching a value of 0.78, is obtained for the less C-containing $Co_{54}Pt_{46}$(5Å)/C(3Å) sample whereas a higher coercivity (5.4 kOe) is observed for the higher C-content $Co_{54}Pt_{46}$(5Å)/C(5Å). The loops were measured with the applied field in the film plane. Thus the remanence enhancement above the value expected (0.5) for randomly distributed uniaxial single-domain particles [5] must be attributed to interparticle interaction effects. In figure 2 (a-c) the demagnetization curves for $Co_{54}Pt_{46}$/C samples annealed at 700°C for 5-30 min with various layer thickness are shown. For longer annealing times the coercivity increases but the M_r/M_S ratio decreases and finally a shoulder in the demagnetization curves develops after long annealing times. This shoulder is more pronounced in samples with higher Pt content ($Co_{45}Pt_{55}$) where it develops even for short annealing times. There are several possibilities for this behavior. One of them may be related to the formation of large multidomain particles. The other reasons may be related to the formation of fcc CoPt phases, which form during aging. An indication for the $CoPt_3$ phase is the fact that the shoulder is more pronounced in samples with higher Pt content. Furthermore these Pt-richer samples show a greater reversibility in the demagnetization curves as would be expected in nanocomposite magnets where the soft-phase exchange coupled to the magnetically hard fct-CoPt phase [6]. Figure 3 shows magnetic data on FePt/C samples with different bilayer thickness annealed at 700°C for 10 minutes where the fct-FePt phase was observed. At smaller carbon thickness (3Å) the H_c values were larger and the hysteresis loops showed a higher M_r/M_s ratio (0.82).

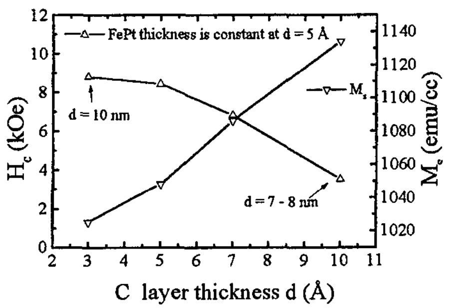

Figure 3. Coercivity and magnetization saturation as a function of carbon layer thickness.

The development of magnetic hysteresis in annealed samples was closely related to the microstructure, which was obtained by transmission electron microscopy. The evolution of microstructure with aging heat treatment at 700°C is shown in figure 4 for the $Co_{54}Pt_{46}$ (5Å)/C(3Å). The as-deposited films were found to consist of tiny particles (5 nm) with the disordered fcc structure (Fig. 4a). Upon aging, the ordered fct phase is formed and the particle size increases. After 10 minutes at 700°C the electron

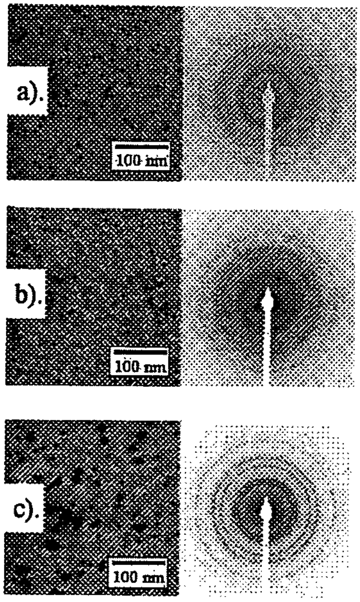

Figure 4. Evolution of micro-stucture of CoPt/C films: (a) as-made, (b). annealed at 700°C for 10 min and (c). annealed at 700°C for 60 min.

diffraction patterns show clearly the presence of ordered peaks corresponding to fct CoPt and the particles grow bigger (7-12 nm) (Fig. 4b). After prolonged heat treatment (60 min) the SAD patterns are more ordered and the particles become larger (8-26 nm) (Fig. 4c). In addition very large (micron size) particles of CoPt are found to coexist with the smaller particles.

An important parameter that is known to determine media noise is the magnetic isolation of the grains. This parameter can be controlled basically by the amount of carbon in the system, which determines the interparticle separation and therefore the interparticle interactions. δM plots [7] have been used to study interaction effects as shown in figure 5. Positive δM ($\delta M_{norm}=M_d-1+2M_r$) indicates the presence of exchange interactions while negative means dipolar interactions. The optimally annealed CoPt(5Å)/C(5Å) sample shows, around H_c, a small amount of positive exchange-type interactions (Fig.5a) superimposed over a negative contribution due to magnetostatic interactions. Positive interactions are completely suppressed in higher C content samples CoPt(5Å)/C(10Å) (Fig.5b) where only the negative magnetostatic part remains. This part of course is difficult to eliminate completely due to the long-range nature of the dipole interactions.

For most of the samples studied the size of the CoPt particles is well below the single domain size of the fct-CoPt phase which is around 0.6 μm, so magnetization reversal should be based on a coherent rotation mechanism. For coherent rotation in a random distribution of non-interacting particles with uniaxial anisotropy K the coercivity is given by $H_c = 0.96K/M_s$ [9]. This would lead to an $H_c \sim 59$ kOe if the bulk value of $K \sim 4.9 \cdot 10^7$ erg/cm^3 is used. The values of the measured coercivity are smaller by one order of magnitude. This large discrepancy may be due to several factors. One could attribute this to the size dependence of coercivity, which for an assembly of randomly orientated non-interacting particles will be [10] proportional to $1-(V_p/V)^{2/3}$ where V_P is the critical volume for superparamagnetism, estimated by $KV_P = 25kT$. Our TEM studies show that particle size is in the range 7-26 nm that would account only for a reduction of coercivity around 20%. Another

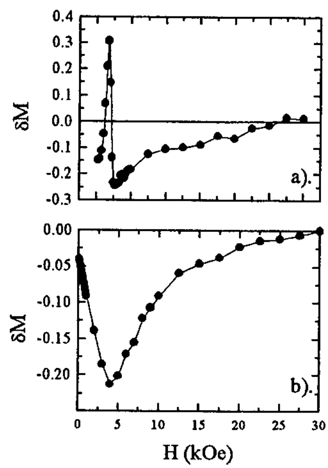

Figure 5. δM plots for (a) $Co_{45}Pt_{55}$ (5 Å) / C (5 Å) and (b) $Co_{45}Pt_{55}$(5 Å) / C (10 Å) samples.

possibility for the explanation of this discrepancy is the consideration of the interaction effects, which are expected to lead to remanence enhancement accompanied by reduction of the coercivity [11]. However, for interactions large enough to give M_r/M_s = 0.78 the expected reduction of coercivity is around 10% [12]. Therefore, inetraction effects may lead to some coercivty reduction in the samples where the grains are not magnetically isolated but cannot explain the large difference that is observed even in samples with isolated grains. This difference must be attributed mainly to the fact that for the relatively short annealing times, which are used to optimize the microstructure, the ordering of the fct phase is not complete. The splitting of the (002)-(200) reflections in the XRD patterns corresponds to a ratio c/a = 0.99 compared to the bulk value of c/a = 0.97. Because of this the anisotropy is expected to be lower than that of the bulk value.

4. **Conclusions**

In summary, we were very successful in fabricating high coercivity CoPt/C and FePt/C granular films consisting of highly anisotropic ordered fct CoPt or FePt nanoparticles embedded in an amorphous C matrix. The particle size and isolation and therefore the coercivity of the films can be varied by controlling the layer thickness and the aging heat treatment conditions. The results of this study are very promising and make these materials attractive as candidates for magnetic recording.

5. Acknoledgments

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